Multi-stage facility location and allocation model under uncertain demand and return

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Keywords
Closed Loop Supply Chain, Uncertainty, Multi-period, Mixed Integer Linear Programming and Product Recovery

Abstract
Customer demands and returns are fluctuating, thereby causing an uncertain environment. Many researchers and the manufacturers are trying to propose suitable network to adopt uncertainty. In this paper, a multi-stage, multi-product capacitated closed loop supply chain (CLSC) network is proposed with objective to optimize the total supply chain cost. To handle the uncertain parameters a scenario-based mixed integer linear programming was developed. Scenarios were framed by changing the demand, return rate, reprocessing rate, reassembling rate, and disposal rate. Totally, 125 scenarios were analysed and effect on the percentage change in total cost was studied. The model is solved using CPLEX, an optimization tool. Computational properties and complexities in solving the problems are studied. Some insights are provided for the model based on different scenarios.

1. Introduction
Customers have enough knowledge about the dangers around them like depletion of natural resources, population growth and environment impact, which has made the customers to buy environmentally friendly products. In recent years, the manufacturers are forced to switch to reverse or CLSC to adopted the concept of green and product recovery. Both these concepts have become an important business strategy to reduce the landfill waste, increase their image in this competitive environment and to have some economic advantage.

Reverse Logistics a part of CLSC is used to recapture the product values and related information from the customer to the manufacturer (Rogers and Tibben-Lembke, 1998) and it is the fundamental part of green supply chain management. Legislative, environmental and economic reasons have augmented the importance of reverse logistics in the last two decades. Manufacturing and re-manufacturing should be integrated in a CLSC by the manufacturer to trade off between parts recovered from the return products and the new purchased from the external supplier. Integration of manufacturing and re-manufacturing makes the CLSC more complex. In addition to the complexity the quality, quantity and timing of return are uncertain which make the system more complicated (shi et al., 2011). These uncertain parameters affect the processing and set-up cost at various facilities. Uncertainty in CLSC has attracted many researchers to investigate on it. Along with return uncertainty, there is supply and demand uncertainty. These uncertainties occur due to delay or mistake by the supplier and improper forecast of demand or volatility of demand(Davis, 1993; Snyder, 2006; Zhang and Ma, 2009). Minimizing the total cost in this uncertain environment has become challenging as the trade-off between parts recovered and parts purchased as well as the location and allocation of facilities have become more difficult.

In this paper, a multi-product, multi-period, multi-facility capacitated CLSC network is proposed. The objective is to minimize the total cost by the trade-off between parts recovered and parts purchased. To handle the uncertain parameters a scenario-based mixed integer linear programming was developed. Scenarios were framed by changing the demand, return rate, reprocessing rate, reassembling rate, and disposal rate. Totally, 125 scenarios were analysed and
effect on the percentage change in the total cost was studied. The model in solved by using CPLEX, an optimization tool.

The outline of this paper is as follows. A detailed literature review of various CLSC with uncertainty are presented in section 2. Proposed CLSC network description and its mathematical model are presented in section 3. In section 4 data description and solution approach is presented as computation experiment. Results and discussions are presented in section 5. In section 6 presents the conclusion and future scope.

2. Literature Review

The concept of CLSC network is used to obtain a competitive advantage in the global market and also useful in operational and strategic decision making. Most of these strategically and operational aspect in CLSC have been analysed in past decades. Issues like wastage, shortages, unsatisfied customers, facility location, depletion of natural resources and environmental effect are studied and optimized by many researchers in the past decades considering real life problems. Time taken to optimize these problems is more as these problems are complex and hard to solve with exact solution approach. Reduction of time is attained by some efficient search methods like approximation algorithms and heuristics methods. Some of the work related to CLSC, re-manufacturing, and uncertainty with or without heuristics are presented below.

In the closed loop system, the balance between demand and the uncertain return has to be considered along with production process by the manufacturer. Inderfurth (2005) identifies that uncertainties have to be considered for balancing of demand and return under a closed-loop system. Kim et al. (2006) considered refurbishment and disposal of parts after disassembling the return products. In this model, the capacity of collection centre, disassembly centre and refurbish centre are considered as uncertain. Mutha and Pokharel (2009) developed a location and allocation model with uncertainty in quantity of return, disposal to recycling percentage, and capacity of the processing centre. Shi et al. (2011) considered demand and return are uncertain and developed a model to investigate a CLSC network. Lagrangian relaxation method was used to optimize the model.

Ozceylan et al. (2013 a) optimized the production and distribution planning for a CLSC network considering a realistic trade-off between the purchasing and refurbishing. For the same model Ozceylan et al. (2013 b) addressed the fuzziness, capacities, demands, objective functions, landfilling and the recovery rate are identified with uncertain parameters. Jindal and Sangwan (2014) proposed CLSC framework in the uncertain environment. Jyoti Darbari et.al. (2015) implemented traveling salesman problem between manufacturing facility and distribution centre in the network under fuzzy environment. Akbari and Karimi (2015) developed a new robust optimization approach for design and planning of a multi-echelon, multi-product, multi-period supply chain network considering process uncertainty with two possibly disjoint uncertainty set.

Almaktoom et. al. (2015) developed a novel robust design optimization to integrate the supply strategy and role of service level for achieving an efficient and cost-effective system. Dubey et al. (2015) proposed a responsive sustainable supply chain network with uncertainty and optimized using robust optimization. Entezaminia et al. (2016) proposed a aggregate production planning problem in a green supply chain considering uncertainty and optimized using a robust optimization approach. Author have also considered a case of Iranian Wood and Paper Industry Company to indicate the practicability of the proposed model.

Based on the above literature, it is identified that there is a research potential to make use of a CLSC network with multi-parts/components under a time horizon with the incorporation uncertainty in demand, return rate, reprocessing rate, reassembling rate, and disposal rate. Therefore, this paper proposes a capacitated CLSC network with multi-product, multi-period, multi-facility. It also considered uncertainty in demand, return rate, reprocessing rate, reassembling rate and disposal rate. The objective of the model is to optimize the total cost considering trade-off between parts recovered and new parts purchased. The model is investigated with different
scenarios by changing the demand, return rate, reprocessing rate, reassembling rate, and disposal rate. These scenarios will be analysed to study the effect of uncertainty.

3. Network Description

A generalized network with the forward flow, reverse flow, and their integration is proposed for handling the multi-products return. The proposed CLSC network is shown in figure 1. In this work, manufacturing of parts will take place in the processing unit and the parts will be assembled to products in the assembling unit. The division of processing and assembling units make the network more realistic as the market has become global. The assembled products will be sent to the customers through the distribution hubs and retailers. Collection of used product from the customer is the beginning of the reverse flow.

The products collected from the customer zone will be a percentage $\eta$ of demand and done by the retailer. The demand must be completely satisfied for each customer zone and the retailer must collect the returned products from the customer zone.

The products collected by the retailers will be sent to sorting and dismantling units. In sorting and dismantling units the products will be disassembled into parts. Along with disassembling the parts will be inspect and sort. The sorted and inspected parts will be divided into three categories like reassemble, reprocessable and disposable. The reassemble, reprocessable and disposable will have $\nu$, $\Psi$, and $\lambda$ percentage of the returned product respectively. The parts which can be used directly without any processing (reassemble) and can be used after processing (reprocessable) will be sent to assembling units and reprocessing units respectively. The rest of the parts will be disposed off. The reprocessed parts will be of same conditions as the new ones. New parts from the reprocessing units will be sent to the assembling units and used for assembling in the next period. Two products are assembled with different parts and detailed bill of the material is given in figure 2. Here, it is assumed that

- The demand for the product is uncertain and must be fully satisfied for multi-periods,
- Inventory costs are not considered in the model as the storing period for parts is assumed negligible for all periods (Ozceylan and Paksoy, 2013 a)
- Facilities capacities are limited and fixed in the network, all the costs are deterministic and known a prior,
- The collection, disposal, and disassembly rates are uncertain,
- The reprocessed part has the same quality as the new part,
- Only parts can be disposed or reprocessed, and
- Wang and Hsu (2011) pointed the recovery amount is calculated as a percentage of customer demand.

![Fig. 1: The Proposed CLSC network](image)
4. Mathematical Model

The network can be formulated as a scenario-based mixed integer linear programming model. Indices, parameters and variables are defined as follows.

Indices

- $l$: Supplier
- $a$: Assembling Units
- $r$: Retailers
- $x$: Reprocessing Units
- $i$: Raw Materials
- $k$: Products
- $w$: Sorting and Dismantling Units (SD)
- $m$: Time Period
- $u$: Scenario

Variables

- $Q_{ilp}^m$: Quantity shipped from Supplier $l$ to Processing Unit $p$ for Raw Material $i$ in period $m$
- $Q_{pja}^m$: Quantity shipped from Processing Unit $p$ to Assembling Unit $a$ for Part $j$ in period $m$
- $Q_{kan}^m$: Quantity shipped from Assembling $a$ to Distribution Hub $n$ for Product $k$ in period $m$
- $Q_{knr}^m$: Quantity shipped from Distribution Hub $n$ to Retailer $r$ for Product $k$ in period $m$
- $Q_{c_kr}^m$: Quantity shipped from Retailer $r$ to Customer $c$ for Product $k$ in period $m$
- $Q_{r_kw}^m$: Quantity shipped from Customer $c$ to retailer $r$ for Product $k$ in period $m$
- $Q_{krw}^m$: Quantity shipped from Retailer $r$ to SD Unit $w$ for Product $k$ in period $m$
- $Q_{r_ky}^m$: Quantity shipped from SD Unit $w$ to Disposal Unit $y$ for Part $j$ in period $m$
- $Q_{jwx}^m$: Quantity shipped from SD Unit $w$ to Reprocessing Unit $x$ for Part $j$ in period $m$
- $Q_{x_aja}^m$: Quantity shipped from Reprocessing Unit $x$ to Assembling Unit $a$ for Part $j$ in period $m$
- $UP_{p}^m$: If the Processing Unit $p$ is open in period $m$, 1; otherwise, 0
- $UA_{a}^m$: If the Assembling Unit $a$ is open in period $m$, 1; otherwise, 0
- $UN_{n}^m$: If the Distribution Hub $n$ is open in period $m$, 1; otherwise, 0
If the Retailer $r$ is open in period $m$, $1$; otherwise, $0$  
If the SD Unit $w$ is open in period $m$, $1$; otherwise, $0$  
If the Reprocessing unit $x$ is open in period $m$, $1$; otherwise, $0$  
If the Disposal Unit $y$ is open in period $m$, $1$; otherwise, $0$

Parameters  
$C_{il}^m$ Capacity of Supplier $l$ in period $m$  
$C_P^m$ Capacity of Processing Unit $p$ in period $m$  
$C_A^m$ Capacity of Assembling Unit $a$ in period $m$  
$C_N^m$ Capacity of Distribution Hub $n$ in period $m$  
$C_R^m$ Capacity of Retailer $r$ in period $m$  
$C_W^m$ Capacity of Sorting and Dismantling Unit $w$ in period $m$  
$C_X^m$ Capacity of Reprocessing Unit $x$ in period $m$  
$S_{ij}$ Stake of Raw Material $i$ in Part $j$  
$S_{jk}$ Stake of Part $j$ in Product $k$  
$dem^m_{cu}$ Demand of Customer $c$ in period $m$ for $u$ scenario  
$f_p^o$ The fixed opening cost for Processing Unit $p$  
$f_a^o$ The fixed opening cost for Assembling Unit $a$  
$f_n^o$ The fixed opening cost for Distribution Hub $n$  
$f_w^o$ The fixed opening cost for Sorting and Dismantling Unit $w$  
$f_x^o$ The fixed opening cost for Reprocessing Unit $x$  
$f_y^o$ The fixed opening cost for Disposal Unit $y$  
$f_{il}$ The unit cost of purchasing of Raw Material $i$ from supplier $l$  
$f_{jp}$ The unit cost of processing of Part $j$ in Processing Unit $p$  
$f_{ka}$ The unit cost of assembling of Product $k$ in Assembling Unit $a$  
$f_{kn}$ The unit cost of sorting and packing for Product $k$ in Distribution Hub $n$  
$f_{kw}$ The unit cost of sorting and dismantling of Product $k$ in SD Unit $w$  
$f_{jy}$ The unit cost of disposal of Part $j$ in Disposal area $y$  
$f_{jx}$ The unit cost of reprocessing of Part $j$ in Reprocessing Unit $x$  
$T_{kan}$ The unit cost of shipping from Assembling Unit $a$ to Distribution Hub $n$ for Product $k$  
$T_{knr}$ Shipping cost per unit from Distribution Hub $n$ to Retailer $r$ for product $k$  
$T_{krw}$ Shipping cost per unit from Retailer $r$ to SD Unit $w$ for Product $k$  
$T_{jwy}$ Shipping cost per unit from SD Unit $w$ to Disposal Unit $y$ for Product $k$  
$T_{jwx}$ Shipping cost per unit from SD Unit $w$ to Reprocessing Unit $x$ for Product $k$  
$T_{jwa}$ Shipping cost per unit from SD Unit $w$ to Assembling Unit $a$ for Product $k$
$\eta_u$ Percentage of demand, which is collected by Retailer from Customer for $u$ scenario

$\lambda_u$ Percentage of disassembled amount which is disposed for $u$ scenario

$v_u$ Percentage of disassembled amount resend to Assembling Unit for $u$ scenario

**Objective Functions**

Min Total Cost $Z =$

$$\left( \sum_{k_{\text{kan}}} Q_{k_{\text{kan}}} A_{k_{\text{kan}}}} + \sum_{k_{\text{kmn}}} Q_{k_{\text{kmn}}} N_{k_{\text{kmn}}}} + \sum_{k_{\text{krw}}} Q_{k_{\text{krw}}} R_{k_{\text{krw}}}} + \sum_{j_{\text{yvw}}} Q_{j_{\text{yvw}}} Y_{j_{\text{yvw}}}} + \sum_{j_{\text{yv}}w} Q_{j_{\text{yv}}w} T_{j_{\text{yv}}w}} \right) + \left( \sum_{p_{\text{fp}}} f_{p_{\text{fp}}} U_{p_{\text{fp}}}} + \sum_{a_{\text{am}}} f_{a_{\text{am}}} A_{a_{\text{am}}} \right)$$

$$\sum_{m_{\text{m}}} f_{m_{\text{m}}} U_{m_{\text{m}}} + \sum_{r_{\text{mn}}} f_{r_{\text{mn}}} R_{r_{\text{mn}}} + \sum_{w_{\text{w}}} f_{w_{\text{w}}} W_{w_{\text{w}}} + \sum_{x_{\text{x}}} f_{x_{\text{x}}} X_{x_{\text{x}}} + \sum_{y_{\text{y}}} f_{y_{\text{y}}} Y_{y_{\text{y}}} \right) + \left( \sum_{m_{\text{m}}} Q_{m_{\text{m}}} S_{m_{\text{m}}} + \sum_{r_{\text{nr}}} Q_{r_{\text{nr}}} R_{r_{\text{nr}}} + \sum_{j_{\text{jw}}x} Q_{j_{\text{jw}}x} T_{j_{\text{jw}}x} \right)$$

$$\sum_{k_{\text{km}}} Q_{k_{\text{km}}} A_{k_{\text{km}}} + \sum_{k_{\text{kn}}} Q_{k_{\text{kn}}} N_{k_{\text{kn}}}} + \sum_{r_{\text{rn}}} Q_{r_{\text{rn}}} N_{r_{\text{rn}}} + \sum_{w_{\text{w}}} Q_{w_{\text{w}}} R_{w_{\text{w}}} + \sum_{x_{\text{x}}} Q_{x_{\text{x}}} X_{x_{\text{x}}} + \sum_{y_{\text{y}}} Q_{y_{\text{y}}} Y_{y_{\text{y}}} \right)$$

Constraints

$$\sum_{p_{\text{ip}}} Q_{p_{\text{ip}}} \leq C_{p_{\text{ip}}} + \sum_{i_{\text{il}}} , \forall i, l, m$$

$$\sum_{a_{\text{ja}}} Q_{a_{\text{ja}}} \leq C_{a_{\text{ja}}} + \sum_{j_{\text{jp}}} , \forall j, p, m$$

$$\sum_{n_{\text{kn}}} A_{n_{\text{kn}}} \leq C_{n_{\text{kn}}} + \sum_{k_{\text{kn}}} , \forall k, a, m$$

$$\sum_{r_{\text{rn}}} N_{r_{\text{rn}}} \leq C_{r_{\text{rn}}} + \sum_{n_{\text{rn}}} , \forall k, n, m$$

$$\sum_{w_{\text{kr}}} R_{w_{\text{kr}}} + \sum_{c_{\text{kc}}} C_{c_{\text{kc}}} \leq C_{r_{\text{kr}}} + \sum_{w_{\text{kr}}} , \forall k, r, m$$

$$\sum_{j_{\text{y}}} Q_{j_{\text{y}}} + \sum_{x_{\text{y}}} Q_{x_{\text{y}}} + \sum_{a_{\text{y}}} Q_{a_{\text{y}}} \leq C_{w_{\text{y}}} + \sum_{w_{\text{y}}} , \forall j, w, m$$

$$\sum_{a_{\text{ja}}} X_{a_{\text{ja}}} \leq C_{j_{\text{ja}}} + \sum_{x_{\text{ja}}} , \forall j, x, m$$

$$\sum_{r_{\text{kr}}} R_{r_{\text{kr}}} \geq \sum_{c_{\text{ku}}} , \forall k, c, m$$

$$\sum_{c_{\text{kr}}} \sum_{k_{\text{kr}}} = \eta_u \sum_{k_{\text{kr}}} + \sum_{k_{\text{kr}}} , \forall k, r, m$$

$$\sum_{l_{\text{il}}} \sum_{p_{\text{ip}}} (\sum_{j_{\text{ja}}} ) \sum_{j_{\text{ja}}} = 0 , \forall i, p, a, m$$

$$\sum_{p_{\text{ja}}} Q_{p_{\text{ja}}} + \sum_{w_{\text{ja}}} Q_{w_{\text{ja}}} - \sum_{x_{\text{ja}}} Q_{x_{\text{ja}}} + \sum_{a_{\text{ja}}} Q_{a_{\text{ja}}} + (\sum_{j_{\text{ja}}} ) = 0 , \forall j, a, n, m$$

$$\sum_{a_{\text{ja}}} A_{a_{\text{ja}}} - \sum_{r_{\text{al}}} Q_{r_{\text{al}}} = 0 , \forall k, n, m$$

$$\sum_{n_{\text{kn}}} N_{n_{\text{kn}}} + \sum_{c_{\text{kr}}} C_{c_{\text{kr}}} - \sum_{w_{\text{kr}}} Q_{w_{\text{kr}}} = 0 , \forall k, r, m$$

$$\sum_{r_{\text{kr}}} (\sum_{k_{\text{kr}}} ) \sum_{k_{\text{kr}}} = 0 , \forall k, w, m$$

$$\sum_{r_{\text{kr}}} (\sum_{k_{\text{kr}}} ) \sum_{k_{\text{kr}}} = 0 , \forall k, w, m$$
\{(1 - v_{ik} - \lambda_{ik}) \sum_{j} QR_{kjw} \} * SJ_{jk} - \sum_{x} QW_{jwx} = 0, \forall j, k, w, m \tag{9.17}

\sum_{w} QW_{jwx} - \sum_{a} QX_{jxa} = 0 , \forall j, x, m \tag{9.18}

Q^{m}_{ijp}, Q^{m}_{up}, Q^{m}_{ax}, Q^{m}_{nx}, Q^{m}_{knr}, Q^{m}_{xw}, Q^{m}_{yw}, Q^{m}_{jwa}, Q^{m}_{xwa} \geq 0 \tag{9.19}

UP_{p}, UA_{w}, UN_{n}, UR_{x}, UW_{w}, UX_{x}, UY_{y} = \{0,1\} \tag{9.20}

The objective is to minimize total cost in the supply chain. The total cost objective has five components. Total transportation cost of CLSC network is represented is the first component, the setup cost of different facilities in the chain is the second component, the logistics cost of the chain is the third component, Raw material purchase cost of the chain is the fourth component and Reprocessing cost of the chain is the final component. Constraints (9.02)-(9.08) ensure that the production and transportation amount must not surpass the capacity of all the facilities respectively. Constraint (9.09) ensures that demands fully satisfied for both the products. Constraints (9.10)-(9.18) are the balance equations for the forward and reverse facilities. Constraint (9.19) enforces the positivity of decision variables. Finally, Constraint (9.20) represents the binary variables.

5. Solution Approach

The model can be solved using an exact method or heuristic method. In Exact method the solution obtained will be optimal and running time will be more for a real or complex problem. In the heuristic method the solution obtained will be the best solution, not the optimal but running time will be less for a real or complex problem. In this section exact method is used to optimize the complex problem with different scenarios to deal with uncertainty.

Exact Method

ILOG CPLEX solver was developed by ILOG and acquired by IBM in 2009. ILOG CPLEX uses logarithmic barrier and sifting algorithm to solve the mathematical model. ILOG CPLEX solver was used to obtain the optimal solution. ILOG CPLEX solver is used for solving linear programs and its extensions.

6. Computational Experiments

In this section, the result of a realistic proposed CLSC network consist of 5 suppliers, 3 processing units, 2 assembling units, 2 distribution hubs, 4 retailers, 2 SD units, 1 reprocessing unit, and 1 disposal unit are illustrated. Computational properties and complexities of solving the problem are studied. Some insights are provided for the model based on different scenarios. Some insights are provided for the model based on different scenarios.

Description of data

The network constitutes a sample problem of 5 suppliers, 3 processing units, 2 assembling units, 2 distribution hubs, 4 retailers, 2 SD units, 1 reprocessing unit, and 1 disposal unit. Five kinds of ram material that have different utilization rate is supplied by suppliers, which in turn, are converted into four parts in processing units. 125 scenarios are considered by varying the demand, return rate, disposal rate, reprocessing rate and reassembling rate. Scenarios are given in Table 1.

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<thead>
<tr>
<th>Sl. No</th>
<th>Demand</th>
<th>Return Rate</th>
<th>Reassembling Rate</th>
<th>Disposal Rate</th>
<th>Sl. No</th>
<th>Demand</th>
<th>Return Rate</th>
<th>Reassembling Rate</th>
<th>Disposal Rate</th>
<th>Sl. No</th>
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<th>Return Rate</th>
<th>Reassembling Rate</th>
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<td>6000,4000</td>
<td>10</td>
<td>50</td>
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<td>10</td>
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<td>50</td>
<td>30</td>
<td>20</td>
<td>85</td>
<td>6900,4600</td>
<td>20</td>
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<td>30</td>
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<td>6300,4200</td>
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<td>50</td>
<td>20</td>
<td>87</td>
<td>6900,4600</td>
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Table 1 Test Scenarios

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<th>Parameters</th>
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<tr>
<td>$CS^m_{il}$</td>
<td>40000</td>
<td>$f_{il}$</td>
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<td>Distance between $l$ and $p$</td>
<td>200-300</td>
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<tr>
<td>$CP^m_{jp}$</td>
<td>40000</td>
<td>$f_{jp}$</td>
<td>Uniform (22-29)</td>
<td>Distance between $p$ and $a$</td>
<td>130-150</td>
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<tr>
<td>$CA^m_{ka}$</td>
<td>5000</td>
<td>$f_{ka}$</td>
<td>Uniform (12-14)</td>
<td>Distance between $a$ and $n$</td>
<td>60-100</td>
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<tr>
<td>$CN^m_{kn}$</td>
<td>5000</td>
<td>$f_{kn}$</td>
<td>Uniform (2-3)</td>
<td>Distance between $n$ and $r$</td>
<td>60-80</td>
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<tr>
<td>$CR^m_{kr}$</td>
<td>3000, 2000</td>
<td>$f_{il}$</td>
<td>Uniform (6-10)</td>
<td>Distance between $r$ and $w$</td>
<td>60-80</td>
</tr>
<tr>
<td>$CW^m_{jw}$</td>
<td>3000</td>
<td>$f_{jp}$</td>
<td>Uniform (22-29)</td>
<td>Distance between $w$ and $a$</td>
<td>140-200</td>
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<tr>
<td>$CX^m_{jx}$</td>
<td>10000</td>
<td>$f_{ka}$</td>
<td>Uniform (12-14)</td>
<td>Distance between $w$ and $y$</td>
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<tr>
<td>$CY^m_{jy}$</td>
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Table 2 Parameters and Values

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<th>Parameters</th>
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<td>$f_{jp}$</td>
<td>Distance between $p$ and $a$</td>
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<tr>
<td>$f_{ka}$</td>
<td>Distance between $a$ and $n$</td>
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<td>$f_{kn}$</td>
<td>Distance between $n$ and $r$</td>
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<td>Distance between $r$ and $w$</td>
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<td>$f_{kn}$</td>
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<tr>
<td>$f_{kw}$</td>
<td>Distance between $x$ and $a$</td>
</tr>
<tr>
<td>$f_{jy}$</td>
<td></td>
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</table>

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These four parts are assembled into two products in assembling units. Road transportation is used for shipping products, parts, and raw materials from different facilities. The transportation cost is given as 20 Rs per ton-Km for a general truck. The fixed cost is found to be 200000 Rs, 100000 Rs, 50000 Rs, 75000 Rs, 75000 Rs, and 50000 Rs for processing units, assembling units, distribution hubs, sorting and dismantling units, reprocessing units, and disposal units respectively. The required parameter values are given in Table 2. The MILP formulation (9.01) - (9.20) of the sample instances will be computed on a PC with an Intel i7 2.54GHz processor with 8 GB RAM using CPLEX solver.

Results and Discussions

The total cost was found to be 1,65,61,882 Rs for all periods which include transportation cost, setup cost, and logistics cost for Scenario 3, which is the base scenario. Table 9.3 shows the optimal feasible results and percentage change for different scenarios. Percentage change is obtained by comparing the total cost for the scenario with the total cost of the base scenario. The change is about -19.76 to 18.34. As the return rate increases the total cost decreases and the demand increases the total cost increases. Also when the reassembling rate increase the total cost decreases and the disposal rate increases the total cost is increased.

7. Conclusions

In this paper, an MILP model was framed for a single-objective CLSC with uncertainty (scenario based). The model is optimized using the CPLEX solver. The network constitutes a sample problem of 5 suppliers, 3 processing units, 2 assembling units, 2 distribution hubs, 4 retailers, 2 SD units, 1 reprocessing unit, and 1 disposal unit. Five kinds of raw material that have different utilization rate is supplied by suppliers, which in turn, are converted into four parts in processing units.

125 scenarios are considered by varying the demand, return rate, disposal rate, reprocessing rate and reassembling rate. Percentage change is obtained by comparing the total cost for the scenario with the total cost of the base scenario. The change is about -19.76 to 18.34. As the return rate increases the total cost decreases and the demand increases the total cost increases. Also when the reassembling rate increase the total cost decreases and the disposal rate increases the total cost is increased.

For future research, a heuristic procedure could be developed to solve the scenario-based mixed integer linear programming model at a reasonable time. Other supply chain problem such as capacity expansion, vehicle routing, and dissembling line balancing can be considered in the network design. Additionally, environmental aspect and social aspect are important issue regarding the sustainable supply chain which is not addressed in this paper, therefore in network design these issues can be incorporated. Also, the proposed CLSC network is for a single objective and it can be expanded to multi-objective problem.
Table 3 Optimal feasible results and Percentage change under uncertain environment

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<th>Reprocessing Rate</th>
<th>Reassembling Rate</th>
<th>Disposal Rate</th>
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<th>$k_2 = 4000$</th>
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References


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